CETRA^{2026} 27-30 May 2026, Bol, Island Brač, Croatia
9th International Conference on Road and Rail Infrastructure

PARAMETRIC AND GENERATIVE BIM MODELLING FRAMEWORK FOR RAILWAY TRACK MAINTENANCE USING TRACK GEOMETRY INSPECTION DATA

Márta Holczimer[1], Zoltán Nagy[2], Ákos Vinkó[1]
[1]Budapest University of Technology and Economics, Faculty of Civil Engineering, Department of Road and Railway Engineering, Hungary
[2]University of Technology and Economics, Faculty of Civil Engineering, Department of Photogrammetry and Geoinformatics, Hungary

Abstract

Modern railway infrastructure management relies on large-scale, time-series condition monitoring data obtained through continuous track inspection. To handle these datasets effectively, digital workflows are required to automate processing and integrate geometric and semantic information within a unified modelling environment. This research introduces a parametric and generative BIM modelling framework for creating a semantically enriched 3D railway track model using TrackScan track geometry inspection data. The workflow includes an automated data processing pipeline that combines absolute and relative track geometry measurements to generate the 3D representation of the existing track irregularities. Parametric rules and scripted procedures are used to reconstruct the 3D track layout at a level of detail suitable for maintenance engineering and asset management tasks. In parallel, semantic attributes relevant to track condition, structural characteristics, and maintenance classification are defined and assigned to model elements. The resulting model forms a machine-readable, data-rich digital representation that supports integration into BIM-based maintenance planning and digital twin platforms. The results highlight that automation reduces manual modelling time, increases data consistency, and enhances decision-support capabilities across the railway maintenance lifecycle.

Keywords: InfraBIM, visual programming, dynamo script, generative and parametric design, railway asset management, Autodesk Civil 3D

1 Introduction

Railway operators are subject to growing requirements driven by emerging regulations on infrastructure digitalization. In many countries, public railway investment projects, above a defined budget threshold, now mandate the application of InfraBIM methodologies. This implies that all project phases, from initial concept and design through construction and operation, are executed within a shared data environment, guided by clearly defined Employer's Information Requirements (EIR) and project-specific BIM Execution Plans (BEP). Efficient data exchange across project phases is essential, as each phase requires different data types and levels of detail. Within the InfraBIM framework, Industry Foundation Classes (IFC) based data structures play a central role in enabling interoperable information exchange. The IFC 4.3 object-oriented data schema [1], released in 2024, was primarily developed to support design and construction–oriented use cases. Nevertheless, a fully standardized methodology addressing linear infrastructure asset management is still lacking.

DOI: https://doi.org/10.5592/CO/CETRA.2026.1772

During the maintenance phase, significantly more information is used and generated than can be contained within an InfraBIM model alone. This information must be both machine-readable and human-readable, as well as editable. Therefore, integrating model-based and non-model-based data is essential, which, in practice, requires applying BIM Model-based data-mapping processes and generative, parametric design tools. BIM models can be connected to external information sources through various approaches, including OpenBIM data exchange formats (e.g. COBie [2], COINS [3]) and closed BIM environments relying on visual programming–based workflows.
Seo et al. [4] proposed a COBie 2.4 data structure specification-based solution to export and import user-defined IFC property set data to spreadsheets. Railway maintenance semantics were derived from the Korea Rail Network Authority's guidelines. Autodesk Revit 2016 was used to generate the IFC model, and FME Workbench 2016 facilitated data exchange from the IFC model to the COBie spreadsheet. The DiStellar [5] is an online platform to convert an IFC-based BIM model property sets into an Excel format and enables the assignment of real measurement data to individual model objects. The system then writes the updated attributes from Excel back into the IFC model, ensuring consistent, bidirectional data synchronization. Zita Sampaio et al. [6] developed a Dynamo visual programming-based workflow in Revit to classify track geometry exceedances and visualize them through color-coded representation in a BIM model, in accordance with applicable European standards [7].
This article presents a Dynamo-based visual programming workflow in Autodesk Civil 3D to generate a 3D railway track model capturing track irregularities from relative and absolute geometry measurements and integrating asset management and rail inventory information. In the next section, details are given about the dynamo-script-based generative BIM modelling process using unloaded track geometry measurement data and the enrichment of maintenance-related semantic information in the model. Then, section 3 presents the test results and gives the main conclusions on the considered possibilities of the InfraBIM solution for railway operation and maintenance digitalization workflow.

2 Materials and methods

2.1 Measurements and data pre-processing

The case study investigates a non-operational 2 km single-track suburban railway line in Hungary, chosen for its diverse alignment geometry, varied topography (cuttings and embankments), and accessibility for validation. Initial design inputs were limited to paper-based site plans and profiles; therefore, the alignment was refined through Absolute and Relative Track Geometry surveys using a TrackScan measurement trolley [8]. Absolute Track Geometry (ATG) of the centerline was obtained via a motorized georeferenced total station tracking a prism on the trolley at 3 m intervals and user-defined points (at rail joints), complemented by topographic measurements. Relative Track Geometry (RTG) parameters - track Gauge (G), Cross-Level (CL), Track Twist (T), Longitudinal Level (LL), and Alignment (AL) – were recorded at 25 cm intervals. The data were exported to a standards-compliant CSV dataset with automatic defect flagging, providing the geometric baseline for the Civil 3D–Dynamo parametric model. During the on-site visual inspection, inventory data of the track superstructure were collected, including rail and sleeper manufacturing marks, rail joint and fastening types, and estimated sleeper spacing derived from rail lengths and sleeper counts. The collected information served as input for defining the model's property set data.

2.2 Generative modelling

The generative modelling workflow consists of three main steps (figure 1): (1) data acquisition, (2) 3D model generation, and (3) integration of maintenance and inventory-based semantic information.

Autodesk Civil 3D (2026) served as the primary modelling environment, supported by Subassembly composer and Dynamo-based automation for workflow execution. First, the horizontal and vertical alignment of the track centerline was determined by ATG measurement, followed by the establishment of the left and right rail alignment geometry processing relative to the track centerline. Then, parametric subassemblies were defined considering the existing trackworks on the line as well as offset and elevation targets are defined to follow the relative geometry variation between left and right rails. Corridor model generation was fully automated using dynamo environment. Lastly, assign the available maintenance and semantic information to our generated model.

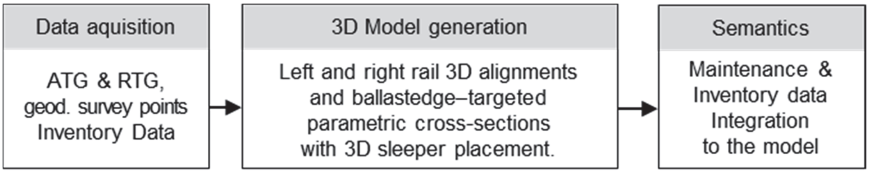


Figure 1 Workflow of generative 3D modelling

2.2.1. Left and right rail 3D alignments

The computational workflow commenced with the resampling of the track centerline to match the 0.25 m recording rate of the Relative Track Geometry (RTG) measurements. At each discrete interval, the tangent vector was computed, while the binormal vector was derived by inclining the local osculating vertical plane according to the measured cross-level value. The normal vector was subsequently established through the cross product of the tangent and binormal vectors. To replicate the track irregularity in real geometric conditions, the theoretical railhead positions were spatially adjusted by applying measured rail alignment and track gauge deviations along the normal vector and vertical level deviations along the binormal vector. These corrected coordinates were then utilized to generate continuous 3D polylines for both rails, serving as the primary target curves for the extrusion of the parametric cross-sections within the final model.

2.2.2 Parametric cross-section

To overcome the limitations of standard Civil 3D libraries and accurately model the current deteriorated condition of the railway superstructure, fully custom subassemblies were developed using Autodesk Subassembly Composer (figure 2). This approach provided the necessary flexibility to construct a detailed, adaptable model capable of replicating the geometric irregularities and features observed in the field.

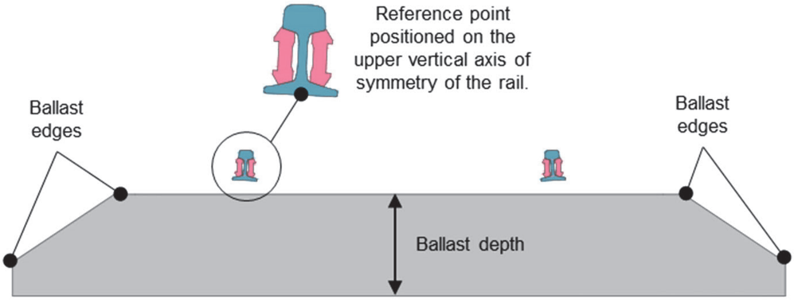
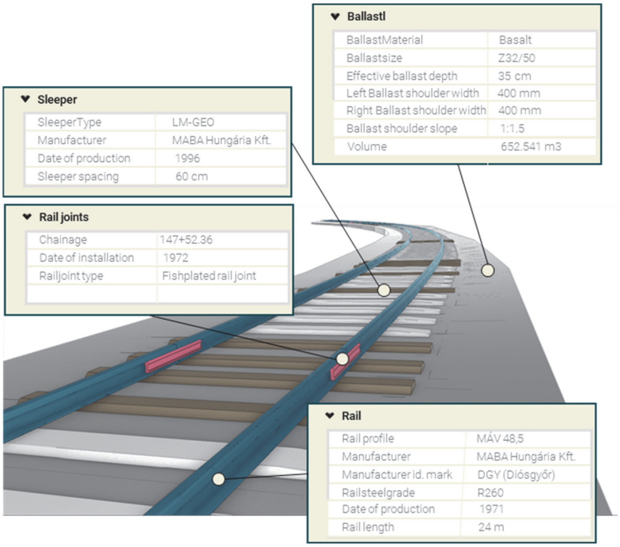


Figure 2 Parametric cross-section implemented in the Subassembly Composer, showing nominal geometric dimensions

A comprehensive set of input parameters was implemented to provide dynamic control of the cross-section. These include geometric parameters defining nominal physical dimensions, such as rail inclination, effective ballast depth, and left and right ballast shoulder widths, as well as enumerated parameter lists enabling logic-based selection of track component types and setting their visibility. The cross-section geometrically represents the rails (MAV 48.5 profile), fish-plated rail joints and ballast bed. Offset and elevation targets represented as 3D polylines were used to define the left and right rail alignments from ATG/RTG measurements, whereas ballast bed edges were controlled using targets derived from geodetic survey points. These parametric components were subsequently imported into Civil 3D to serve as the foundation for precise corridor generation. Utilizing the defined subassemblies and rail alignments, the 3D corridor was parametrically generated and extracted as solid geometry within the Dynamo framework, directly incorporating the collected track observation data.

2.2.3 Assign track maintenance and semantic information

To ensure BIM compliance and facilitate dynamic data linking, the 3D solids derived from the corridor model were enriched with custom metadata through the configuration of Property Sets and the object classification system (figure 3). While standard Civil 3D collections provide limited general information, property set definitions were expanded beyond the default scope to include distinct categories of track components such as ballast, rail, sleepers, and rail joints and their maintenance activities. List definitions were employed to standardize attribute entry (e.g. description of work), thereby ensuring data integrity across the model (table 1). Following the configuration phase, these definitions were systematically assigned to the relevant object classes, including rails, sleepers, and ballast, by associating them with specific 3D entity types. This process enriched the geometric model with semantic attributes, including quantities, volumes, and manufacturer specifications, organized via a structured Classification Definition system. The efficacy of this enrichment was validated through an IFC export; upon inspection in Trimble Connect, the model demonstrated a robust object-oriented structure where each infrastructure component retained its designated semantic properties, confirming the successful integration of geometry and alphanumeric data.



Ballastl

BallastMaterial	Basalt
Ballastsize	Z32/50
Effective ballast depth	35 cm
Left Ballast shoulder width	400 mm
Right Ballast shoulder width	400 mm
Ballast shoulder slope	1:1.5
Volume	652.541 m3

Sleeper

SleeperType	LM-GEO
Manufacturer	MABA Hungária Kft.
Date of production	1996
Sleeper spacing	60 cm

Rail joints

Chainage	147+52.36
Date of installation	1972
Railjoint type	Fishplated rail joint

Rail

Rail profile	MÁV 48,5
Manufacturer	MABA Hungária Kft.
Manufacturer id. mark	DGY (Diósgyőr)
Railsteelgrade	R260
Date of production	1971
Rail length	24 m

Figure 3 Object classification and property set data represented in the Trimble Connect BIM viewer

Table 1 Property set definition for railway maintenance and renewal

Property name (Type)	Attribute
Type of work (Enumerated list)	Renewal
	Maintenance operation
Description of work (Enumerated list)	Track geometry correction (lifting, levelling, aligning and tamping)
	Ballast cleaning
	Rail maintenance (grinding, milling)
	Sleeper replacement
	Overhead electrification equipment maintenance
	Overhead electrification system renewal
Machine / equipment / tools used	User-defined Input
Date of maintenance work	User-defined Input
Duration of work	User-defined Input
Line ID (Enum. list)	Enumerated List
Chainage start point	User-defined Input
Chainage end point	User-defined Input
Quality of maintenance intervention (Enum. list):	Accepted
	Not accepted
Traffic conditions during maintenance (Enum list)	Track possession
	Under traffic

2.3 Track geometry Analysis based on 3D model

Additionally, the integration of the 3D model with relative track geometry data enabled the enhanced visualization of track sections exceeding safety thresholds. The case study applied the operational standards of the Hungarian State Railways, which define three distinct categories: alert (C1), intervention (C2) and immediate action (C3) limits. Accordingly, each rail segment was color-coded to correspond with its specific measured value. Figure 4 illustrates an example of a track section color-coded according to the measured track gauge values.

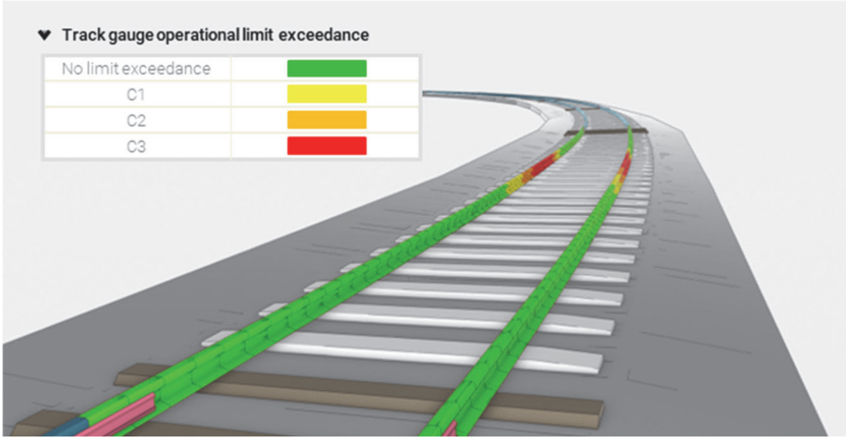


Figure 4 BIM-based track model visualization illustrating track gauge compliance

3 Results

This study demonstrated a parametric generative framework for the automated reconstruction of Building Information Models (BIM) derived from measured track geometry data. By integrating the computational flexibility of the Dynamo visual programming environment with the infrastructure design capabilities of Autodesk Civil 3D, the workflow successfully automated both the generation of complex 3D corridor geometry and the systematic assignment of semantic metadata. Any continuous or discrete linear structure along the railway track, whether parallel to or crossing the center line at an angle, can be handled using the proposed methodology. The Subassembly Composer allows the implementation of cross-sectional variations such as side ditches and drainage elements, while the Dynamo geometric library enables the modelling of structures crossing the railway track, including overpasses, underpasses, and culverts. The resulting methodology exhibits significant transferability, offering a scalable solution applicable to diverse railway infrastructure contexts provided that compatible geometric input data are available.

4 Conclusion

Future research will focus on investigating the computational influence of geodetic coordinate systems, specifically the performance impact of large coordinate magnitudes, on processing speed and user experience. A key objective is to decouple the geometric generation process from the proprietary Autodesk Civil 3D environment. While the current workflow leverages Dynamo's deep integration with Autodesk products, shifting towards Dynamo's standalone open-source capabilities (Sandbox) would significantly enhance the tool's accessibility and transferability. Additionally, the utility of the generated BIM model may be extended to support advanced engineering applications, such as track-rolling stock interaction simulations. The presented framework demonstrates robust capabilities in synthesizing BIM models primarily from tabular datasets. Beyond geometric reconstruction, the workflow successfully incorporates ATG and RTG data directly into the model structure. This semantic integration enables the calculation of various derived parameters directly within the BIM environment, effectively eliminating the reliance on external linked databases or supplementary file systems.

References

[1] ISO 16739-1:2024 - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema

[2] STANDARD – National Institute of Building Sciences, https://nibs.org/nbims/v4/, 26.01.2026.

[3] Nederveen, V., Beheshti, R.: Building Information Modelling in the Netherlands: A Status Report

[4] Seo, K.W., Kwon, T.H., Lee, S.H.: COBie Based Maintenance Document Generation of Railway Track, Journal of the Computational Structural Engineering Institute of Korea, 30 (2017) 4, pp. 307–312, DOI: 10.7734/COSEIK.2017.30.4.307

[5] DiStellar - Free Web IFC Viewer, https://distellar.diroots.com/, 27.01.2026.

[6] Sampaio, Z., Moreira, N., Neves, J.: I-BIM Applied in Railway Geometric Inspection Activity: Diagnostic and Alert, Applied Sciences, 15 (2025) 10, DOI: 10.3390/APP15105733

[7] European Committee for Standardisation, EN 13848-5:2008 Railway applications - Track - Track geometry quality - Part 5: Geometric quality levels - Plain line, http://www.mszt.hu/webaruhaz

[8] Track Geometry I | Metalelektro Measuring Technique Kft. | Budapest, DOI: https://www.metalelektro.eu/track-geometry-i, 29.01.2026.